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Author(s):
Bacon, Jeffrey D.
Spore, Candace K
Milner, Edward Cas
Borozdin, Konstantin
Morris, Christopher
Miyadera, Haruo
Toleman, Nathan F.
Perry, John O.
Chen, Elliott D.
Roybal, Jonathan D.
Busch, Robert
Carpenter, Ken
Hecht, Adam

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Imaging Nuclear Power Reactors with Cosmic – Ray Muons

Jeff Bacon♪, Konstantin Borozdin♪, Robert Busch♫, Ken Carpenter♫, Elliott Chen♫, Adam Hecht♫, Haruo Miyadera♪,
Edward Cas Milner♪, Christopher Morris♪, John Perry♪, Jonathan Roybal♪, Candace Spore♫, and Nathan Toleman♫

♪ Los Alamos National Laboratory, ♫ University of New Mexico, ♫ St. Johns College

Abstract

By using muons – subatomic particles produced by the interactions of cosmic rays in atmosphere – we have developed a technique to image and identify unknown materials. We measure the scattering of muons with particle detectors to determine density and generate images of the objects. One example of planned implementation of muon tomography is the imaging of the damaged reactor cores at Fukushima Daiichi. To demonstrate the capability we will image a core of the research reactor at the UNM. Muon Tomography is a perhaps the only viable way of imaging such reactor cores from outside of the reactor radiation shielding.

Mini Muon Tracker - MMT

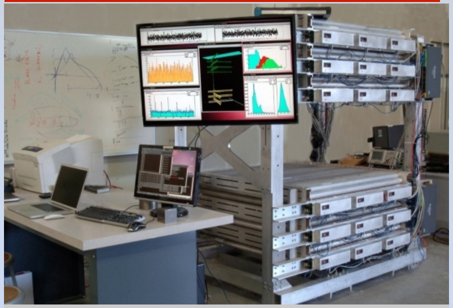


Figure 1. Mini Muon Tracker was built at Los Alamos in collaboration with NSTec and Decision Sciences, Inc.

The Mini Muon Tracker is made up of 576 drift tubes. The drift tubes are filled with an $Ar/CF_4/C_2H_6$ gas mixture. As the muon passes through the gas it ionizes the gas molecules. An electric field between the anode wire in the middle and Al tube separates the created ion – electron pairs and directs the ionization charge to electrodes that collect the signal. This charged impulse is converted into an encoded digital signal.

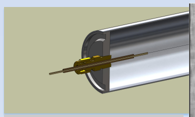


Figure 2. Side view of drift tube.

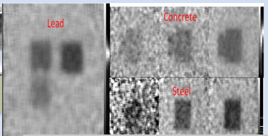


Figure 3. Transmission images for lead, steel and concrete targets.

Both intensity and direction of the cosmic ray are measured with detectors like MMT. The trajectory information can be used to generate a projected transmission image at any distance from the detector. Conceptually, the stopping length λ of cosmic rays in material is inversely proportional to the stopping rate and can be related to the energy spectrum, dN(E)/dE, as

$$1/\lambda = dN/Ndx = 1/N^* \, dN/dE \, ^*dE/dx$$

The energy loss dE/dx, can be calculated using the Bethe – Bloch formula. Over a wide range of momentum, the energy loss for cosmic ray muons varies only logarithmically with momentum and is approximately proportional to the electron density, Z/A.[1]

Fukushima Daiichi Reactor Project

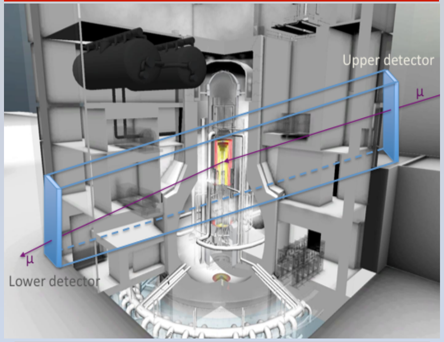


Figure 5. Proposed detector setup for Fukushima Daiichi with two muon trackers ~ 50 m apart. Concept of reactor core imaging with cosmic rays. Two cosmic-ray detectors (shown in blue) should be installed on opposite sides of the reactor building to assess the damage to the core (the melted core is shown in yellow and red). The three-dimensional visualization of the Fukushima Daiichi reactor #1 is done by the VISIBLE team at LANL (http://tiny.cc/toip3).

The Los Alamos Muon Team proposes using muon tomography to investigate the nature of the damage at the Fukushima Daiichi reactor. Muon Tomograhpy (MT) has high sensitivity for high-Z material. Cosmic – ray muons are the results of hadronic showers in the upper atmosphere. Due to the mean energy of several GeV the muons reach the Earth's surface and are highly penetrating. Muons are not attenuated by nuclear interactions and their range in material is only limited by the Bethe-Bloch energy-loss process.

The Mini Muon Tracker (MMT) measures multiple Coulomb scatterings of cosmic ray muons in an object. Muons are deflected at greater angles in higher density material such as uranium. This technique has been applied to practical applications of scanning shipping containers and trailers to detect nuclear materials (Fig.4). The LANL team has demonstrated through mock up demonstrations and GEANT4 simulations that MT imaging will work through thick concrete walls.[2]

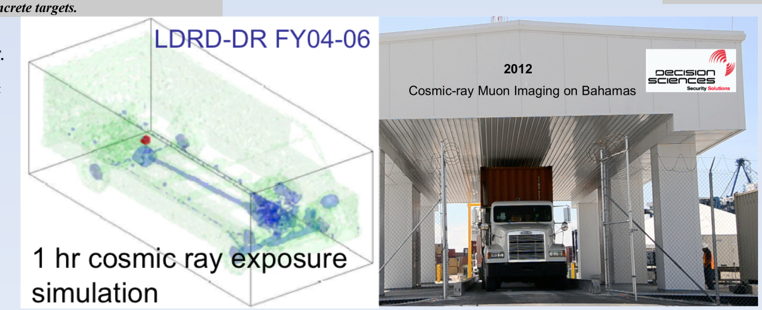


Figure 4. Development of muon tomography at Los Alamos from concept to applications. Left: Image reconstruction of computer- simulated muon scattering data. Image is of a passenger van with a 20-kg uranium sphere. The sphere is shown in read representing highest level of the scattering in the image. Right: LANL technology is commercialized by Decision Sciences, Inc.

University of New Mexico Nuclear Reactor Imaging

The next step in the imaging of nuclear reactors will be an experiment carried out by current collaboration with the University of New Mexico. We will set up the MMT to scan the UNM reactor for a ~one month time frame. During this run the reactor will be operating. This will give practical real data to continue demonstrating the feasibility of using the MT to track muons and make images for Fukushima Daiichi reactor cores.
Through this reactor scan we will be able to measure the impact of low level radiation fields on muon tomography and the reconstruction processes. Radiation levels during reactor operation is ~50mSv/h which is similar to the radiation environment inside shield at Fukushima Daiichi.[4] Gamma ray events can be disseminated by taking time coincidence with other tubes. Since each electronics board on MT read 2 drift tube layers simultaneously, we will implement 2 fold hardware coincidences between the layers to remove the gamma ray events. [3]

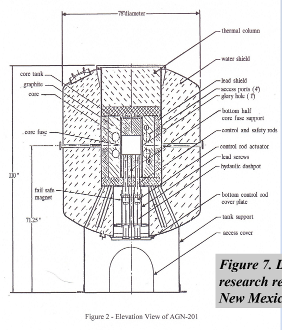
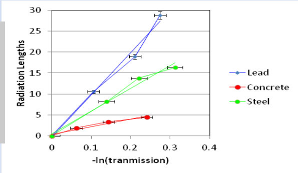


Figure 7. Drawing of the design of the research reactor at the University of New Mexico and its main elements.

Material Identification

Our detectors measure both scattering and transmission. Combining these two signals allows us to distinguish between different materials. Figure 6 illustrates the concept.

Figure 6. Combining measurements of radiation and attenuation lengths of lead, concrete and steel we can distinguish between these different material. The data was obtained by measuring bricks of different thicknesses with the MMT.



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